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THIRD QUARTERLY PROGRESS REPORT

Hydroplaning of Aircraft Tires
15 July 1965

NASA Contract NSR 31003016
DL Project 475/6

Objective

To make a systematic experimental study of the various parameters affecting hydroplaning of aircraft tires, and to seek a quantitative theoretical description of the hydroplaning phenomenon.

Work Completed During the Period 15 April through 15 July 1965

Modification of the rolling road has been completed. The 40hp drive motor, its power supply and control system, and the heavy duty rubber timing belt transmission system all have been installed. The existing roller drums[1] were carefully realigned and dynamically balanced for high speed operation. The road, as now modified, is capable of the 90 ft/sec top speeds required for this study.

A 36-inch wide, .060-inch thick, oriented nylon transparent belt was obtained and installed on the road. Performance to date has been unsatisfactory, mainly because the belt does not run flat on its support table, but develops large longitudinal bulges as high as 1/2-inch. This is obviously not compatible with the necessity to maintain thin, flat water films on the belt surface. In addition to bulging, the belt tends to oscillate laterally. As noted in the previous progress report,[2] this characteristic can be avoided by precise alignment of the belt's transverse joint, and the specifications demanded of the belt supplier reflect this. However, the belt as delivered is not up to these specifications. On these grounds, but primarily because of its bulging tendencies, the belt is regarded as unacceptable, and payment has been withheld. Unfortunately, however, the belt supplier, despite previous assurances that the specifications would be met, now represents the belt supplied to be the best that can be manufactured. From this point of view, the only alternative to the present belt is an opaque belt such as originally installed on the road, a poor alternative as far as the objectives of this study are concerned. For this reason, it has been decided that the present nylon belt should be retained for the time being and efforts be made to overcome its deficiencies. At the same time, attempts are being made to obtain a more satisfactory belt from some other source, in which case the present belt will be returned.

Another problem associated with the nylon belt was discovered during the trial tests with the four-inch wide belt,[2] viz, that high slip between the belt and the roller drums causes a transfer of the drum surface material onto the belt. So far, no way of removing this material has been found. To prevent this material transfer from destroying the transparency of the working area of the belt, the middle twelve inches of the drums have been painted with a hard polyurethane-base paint. Not enough operating experience has been accumulated with the coated drums to date to conclude whether or not the desired effect has been achieved.

The construction of the tire test rig has been completed. The aircraft wheel assembly was modified to accommodate the required range of tire sizes, and equipped with an electric brake, a tachometer, and transducers which measure wheel deflection and drag force. The rig is presently being installed on rails over the rolling road work surface.

The piping system for applying the water film to the rolling road has been completed. Preliminary tests indicate satisfactory operation, however, rigorous testing of accuracy of water film application cannot be conducted until after belt performance is improved.

A plexi-glass window-mirror system which will permit visual observation and photography of the tire footprint has been designed. Installation is being delayed pending exploratory experiments to determine the optimum section of the rolling road for the hydroplaning testing.

Difficulties in obtaining transducers appropriate for measuring tire footprint pressures on the rolling road were mentioned in the previous progress report.[2] Attempts since then have not been encouraging; it appears that development of such a measuring procedure will be both involved and expensive. As of this time, efforts along this line have been suspended for practical purposes.

Exploratory testing of model tires was continued. Static and dynamic tests were made with polyurethane scale models of types I, III and VII aircraft tires. These indicated that polyurethane models with geometric properties similar to pneumatic tires can be produced by existing methods. The effect of inflation pressure is simulated by variation of polyurethane foam density. Pneumatic tire carcass stiffness is simulated by metal side plates which are used to constrain the polyurethane tires. The graphs of Figure 2 illustrate the two effects. Figure 2a compares the static force-deflection characteristics of a Type I 57x20 aircraft tire (scaled down with a λ^3 force scaling law) with corresponding curves for both 10 lb/ft^3 and 18 lb/ft^3 density polyurethane tires. Figure 2b shows the effects of the sideplates on the 18 lb/ft^3 tire. Figure 1 is a photograph of some of the apparatus used in making these tests.

Exploratory tests were also conducted with commercial pneumatic and semi-pneumatic tires. The latter performed very poorly in dynamic tests, with strong vibrating and knocking tendencies. In general, they were very hard and acted more like solid wheels than aircraft type pneumatic tires. The small pneumatic tires behaved much better. Unfortunately, however, the meager number of small sizes commerically available minimizes the potential usefulness of pneumatic tires for a systematic model test program.

It has consequently been decided to utilize polyurethane tires for the main portion of the tests, with the available small pneumatic tires for reference purposes. Work has begun on the fabrication of forty-eight such tires, three of each of the sizes tabulated in the previous progress report,[2] with foam densities ranging from 10 lb/ft^3 to approximately 30 lb/ft^3. It is anticipated that this range will amply cover the size and pressure variations of existing aircraft tires, on the basis of a model scale factor of $\lambda = 1/5$.

A tentative program for the rolling road tests has been drawn up. The basic variables and their projected values are as follows:

1. Tire diameter/width ratio; 1.5, 2.5, 3.5, 4.5.

2. Tire diameter; 4", 6", 8", 10" (20", 30", 40", 50" full scale with $\lambda = 1/5$)*.

3. Tire density; 10, 20, 30 lb/ft^3 (corresponding full scale pressures to be determined on the basis of final dynamic measurements of geometrical properties).

4. Vertical load; 25, 50, 100, 150, 200 lbs (3125, 6250, 12500, 18750, 25000 lb. full scale with $\lambda = 1/5$, λ^3 scaling law).*

5. Water thickness (approximate); 0, .005", .010", .025", .050", .075", .100", .150" (0, .025", .050", .125", .250", .375", .500", .750" full scale with $\lambda = 1/5$).*

6. Tread pattern; 3 different (to be determined).

7. Surface condition; 3 different (to be determined).

In conformance with the original planning for this study,[3] these variables will be investigated essentially in the order listed above.

Because of financial limitations, work has been discontinued on the numerical solution of the integral equations developed to represent the idealized hydroplaning system. However, under the assumptions of low aspect ratio, high Froude number, and a prescribed ground pressure distribution below the planing surface, an analytic solution has been obtained. Comparison of preliminary results with experiments on a flat-bottom planing surface[4] indicates that this approximate theory predicts correctly at least the trend of the hydrodynamic lift. Furthermore, the predicted shape of the pressure distribution strongly indicates the existence of a spin-slowdown moment on a hydroplaning tire.

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* Larger (or smaller) full scale diameters, loads, pressures, and film thicknesses can also be studied by interpreting the same raw model data on the basis of a smaller (larger) scale factor.

A supplemental agreement, Amendment No. 1, to the referenced contract,[5] was issued by NASA (date May 5, 1965) to clarify a discrepancy[6] between the contract and the proposal from which it stemmed.

Plans for Next Quarter

Unexpectedly high costs of modifying the rolling road facility, increases in Davidson Laboratory overhead (from 70% to 78%) and machine shop (from $9.00/hr. to $9.80/hr.) use rates, and a combination of other unforeseen complications have created a situation not uncommon in the initial stages of a program of this nature but nonetheless distressing; shortage of funds.

The unexpended balance of funds on the contract as of 30 June 1965 was approximately $10,000 or one-sixth of the original appropriation. On the other hand, the contract's one year period of performance was less then three-quarters gone, and the completed portion of the original statement of work[3] (if such things can be put in quantitative terms) was perhaps even less advanced.

A proposal for extension of support which reflects this situation is currently being prepared, and will be forwarded to NASA presently. At the same time, work is continuing along lines intended to provide the most meaningful results possible within the remaining funds.

As already noted, the theoretical effort is being concentrated on the pursuit of the promising approximate analytic solution. Systematic calculations are now in progress for comparison with actual tire hydroplaning data obtained previously by NASA.[7] A critical evaluation of the results will be made and conclusions will be drawn as to the effect of the various important parameters such as aspect ratio of the hydroplaning surface, depth of water, angle of attack, tire inflation pressure, etc. A preliminary report discussing the theoretical solution is now being written.

Primary efforts on the experimental phase are naturally being directed towards perfecting the test set-up, in particular towards overcoming the unsatisfactory belt performance. At the same time, instrumentation is being checked out and calibrated. The setup of the tire rig on the rolling road should be completed shortly. At this time, the only impediment to successful operation of the facility for hydroplaning testing appears to be the belt problem. How long it takes to overcome this problem will dictate how much, if any, meaningful testing can be conducted within the existing funds.

References

1. Dugoff, H., "The Davidson Laboratory Rolling Road Facility", Journal of Terramechanics, Vol. 1, No. 4, 1964.

2. Second Quarterly Progress Report, Hydroplaning of Aircraft Tires, NASA Contract NSR 31003016, DL Project 475/6, 15 April 1965.

3. DL Proposal P-286, "Proposal for Research on the Hydroplaning of Pneumatic Tires on Wet Runways", 1 June 1964.

4. Christopher, K.W., "Effect of Shallow Water on the Hydrodynamic Characteristic of a Flat-Bottom Planing Surface", NASA TN 3642, April 1956.

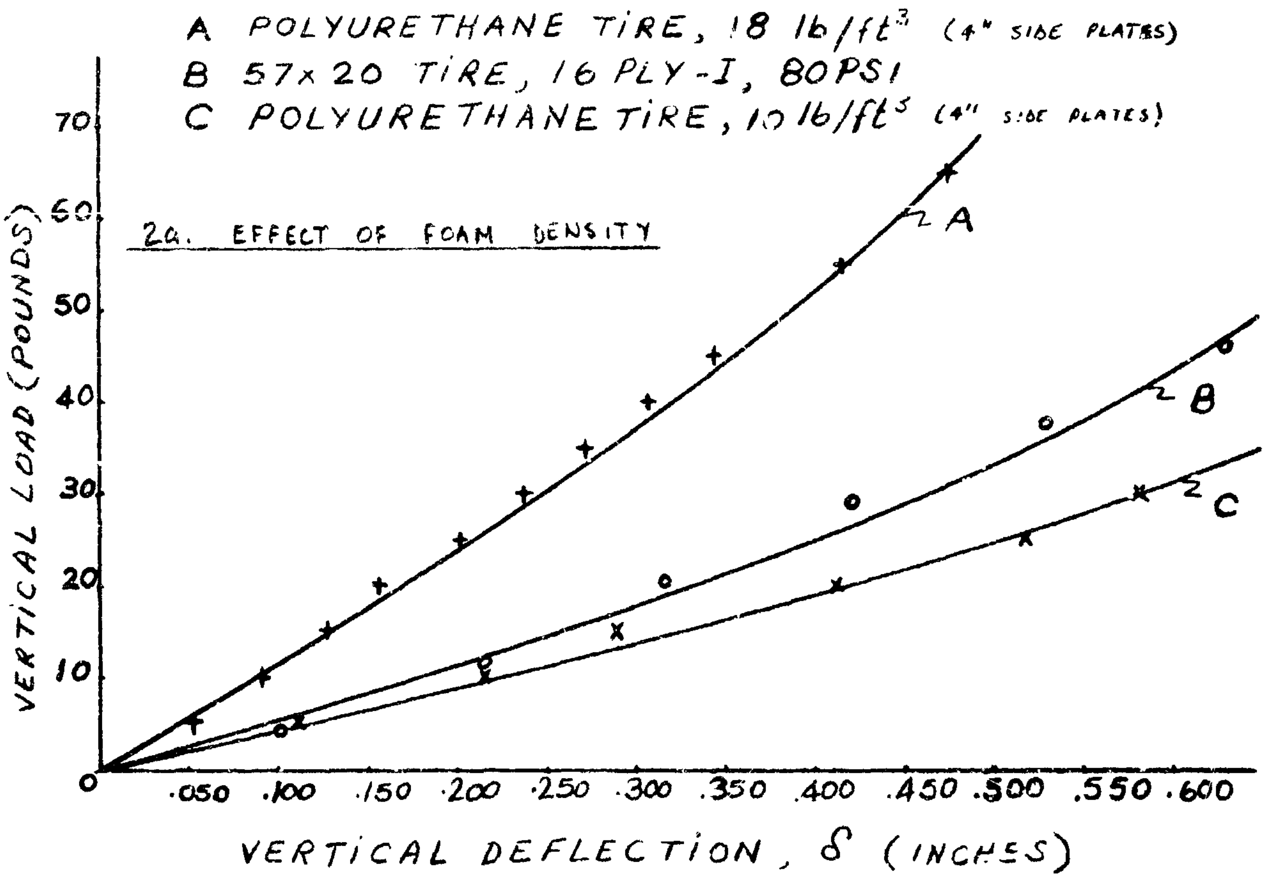
5. NASA Contract No. NSR 31-003-016, "Contract for Theoretical and Experimental Studies of Aircraft Tire Hydroplaning", October 15, 1964.

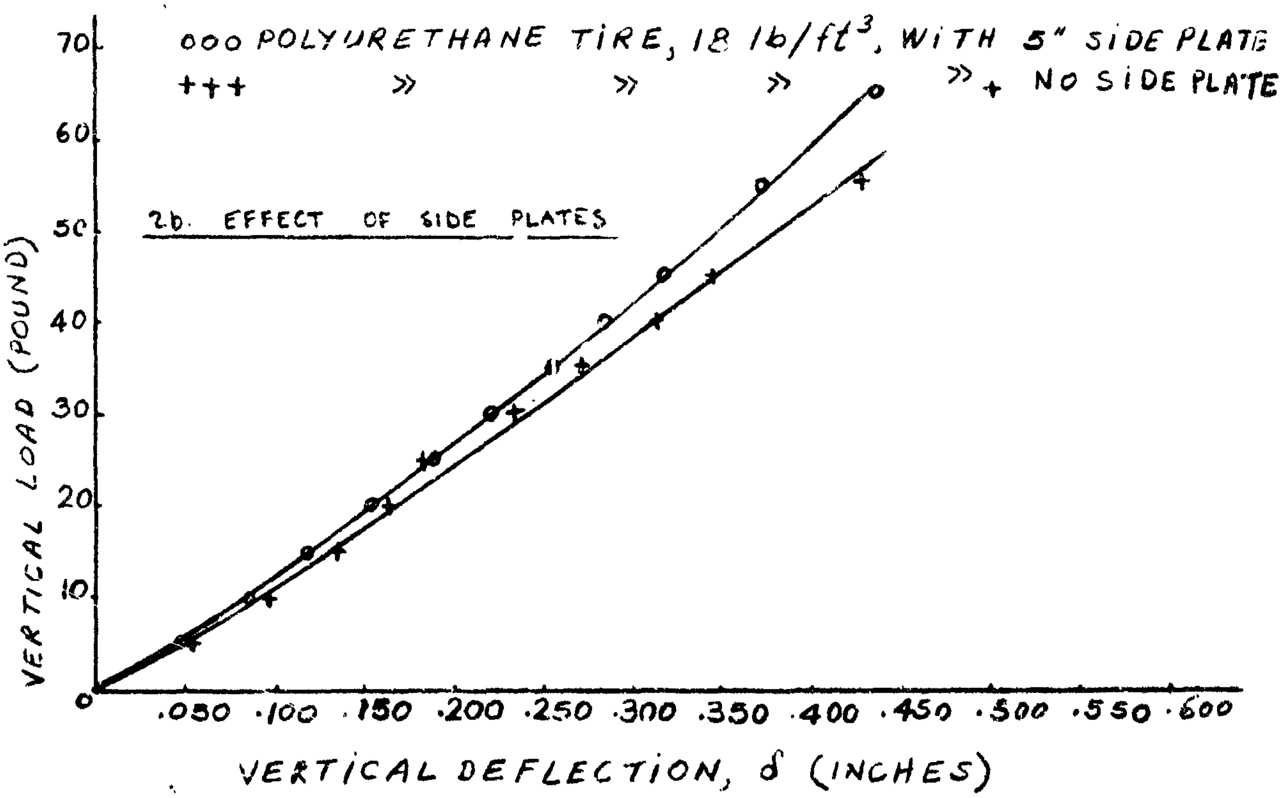
6. Letter, H.W. MacDonald, DL, to Dr. Thomas J. Smull, Office of Grants and Research, NASA, 13 April 1965.

7. Horne, W.B. and Joyner, U.T., "Pneumatic Tire Hydroplaning and Some Effects on Vehicle Performance", SAE 970C, January 1965.

FIGURE 1

STATIC TIRE TEST SETUP WITH SMALL TIRE RIG


A POLYURETHANE TIRE, 18 lb/ft³ (4" SIDE PLATES)
B 57×20 TIRE, 16 PLY-I, 80PSI
C POLYURETHANE TIRE, 10 lb/ft³ (4" SIDE PLATES)
2a. EFFECT OF FOAM DENSITY
VERTICAL LOAD (POUNDS)
0
10
20
30
40
50
60
70
.050 .100 .150 .200 .250 .300 .350 .400 .450 .500 .550 .600
VERTICAL DEFLECTION, δ (INCHES)
A
B
C


000 POLYURETHANE TIRE, 18 lb/ft³, WITH 5" SIDE PLATE
+++ " " " " + NO SIDE PLATE
2b. EFFECT OF SIDE PLATES
VERTICAL LOAD (POUND)
0
10
20
30
40
50
60
70
.050 .100 .150 .200 .250 .300 .350 .400 .450 .500 .550 .600
VERTICAL DEFLECTION, δ (INCHES)